Benthic Habitats of Gray’s Reef National Marine Sanctuary

NOAA National Ocean Service
National Centers for Coastal Ocean Science
Center for Coastal Monitoring and Assessment
Biogeography Team

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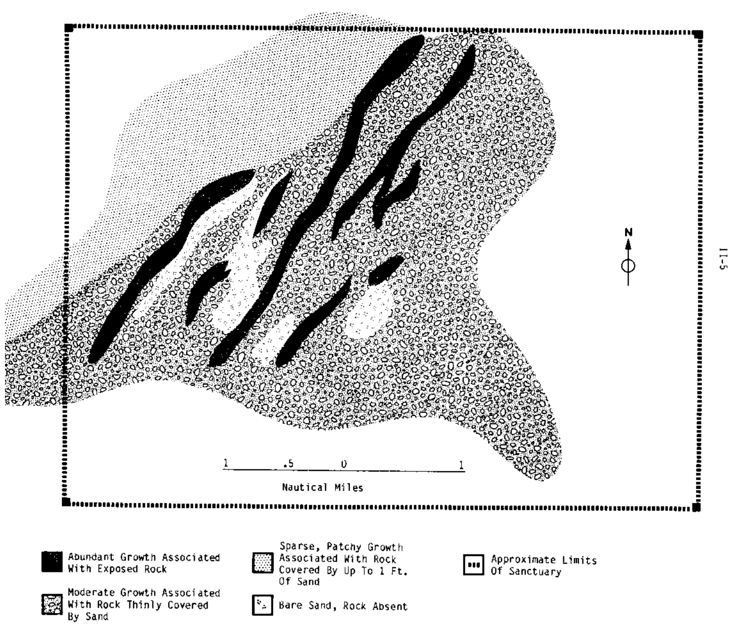
1. NOAA/NOS/NCCOS/CCMA, Biogeography Team; N/SCI 1, SSMC4; 1305 East West Highway; Silver Spring, MD 20910
2. NOAA National Marine Sanctuary Program; Gray’s Reef NMS; 10 Ocean Science Circle; Savannah, GA 31411
3. NOAA/NOS/NCCOS/CCFHR; 101 Pivers Island Road; Beaufort, NC 28516
4. Skidaway Institute of Oceanography; 10 Ocean Science Circle; Savannah, GA 31411

Introduction

Gray's Reef was designated as a National Marine Sanctuary in 1981. It encompasses a 58 km^2 area of sand and rock bottom located 27 km off the coast of Georgia. It was selected as a Sanctuary in part due to the complex mosaic of habitats in the area including sand plains, caves, scarps, and rocky overhangs (Figure 1) which support a diverse assemblage of organisms including approximately 150 species of fish, 200 species of invertebrates, and 65 species of macroalgae. Despite a wealth of investigations on the natural resources of the biota and benthic features of Gray's Reef, only coarse benthic maps of the area have been produced (e.g. Hunt, 1974 below).

NOAA's National Marine Sanctuary Program (NMSP) and specifically Gray's Reef National Marine Sanctuary (GRNMS) require a more detailed baseline characterization of the benthic resources in the Gray's Reef area. Such an assessment is needed to support the many activities and responsibilities of sanctuary staff including natural resources management, education, research, and for promoting responsible recreational use by fishermen and divers. An understanding of the distribution of benthic habitats provides the spatial framework within which to conduct sanctuary monitoring activities, identify and protect essential fish habitat, and properly address other spatially explicit research and management goals. This baseline characterization is also the first step in monitoring temporal changes in the Gray's Reef seascape and understanding more about the dynamic nature of this region of the continental shelf.



To meet this specific need and as part of an effort to characterize the resources of all National Marine Sanctuaries (Biogeography Team, 2003), the National Centers for Coastal Ocean Science (NCCOS), Center for Coastal Monitoring and Assessment's (CCMA) Biogeography Team and its partners mapped benthic habitats of the sanctuary using sonar imagery. Acoustic imaging is a valuable tool for natural resource managers and researchers that require comprehensive maps of bottom features but are unable to use aerial photography or satellite remote sensing technology due to water depth or turbidity. Benthic maps for the sanctuary were developed using a custom GIS application and combined analysis of backscatter from sidescan sonar, bathymetry from multibeam sonar, and video transects.

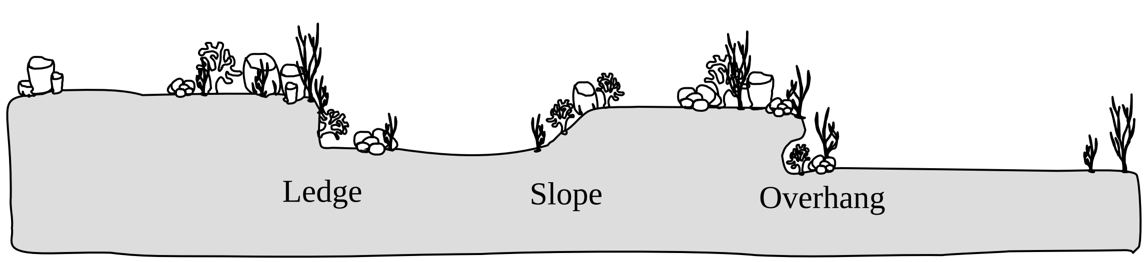


Figure 1. Example cross-section of bottom features (adapted from Hunt, 1974).

Methods

Benthic maps of GRNMS were created by visual interpretation of sonar imagery using the Habitat Digitizer 3.0 extension (Kendall *et al.*, 2001) for ArcView 3.2. The Methods section has been divided into the following subsections: creating sonar mosaics, collecting ground validation and accuracy assessment data, developing the habitat classification scheme, digitizing benthic maps, and assessment of classification accuracy.

Creating Sonar Mosaics

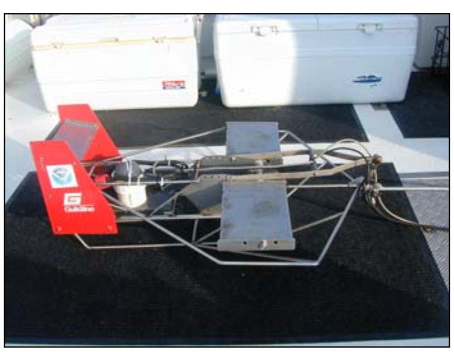
From June 26 to July 4, 2001 sidescan sonar data were acquired by the NOAA Ship Whiting using ISIS Sonar 5.0 acquisition software (TEI, Inc.) and a Klein 5500 sidescan system. Data were collected along north-south (N-S) as well as east-west (E-W) tracklines each with 100 % coverage of the sanctuary respectively such that two backscatter mosaics could be created, one for each of the trackline orientations. Data were collected along lines that crossed the entire sanctuary. Each long transect line was acquired in individual segments 200 megabytes in size to facilitate later data reduction and manipulation. Swathwidth for each segment was approximately150 m with 10 to 30 % overlap between adjacent lines. The backscatter data were archived onto DLT-III tapes onboard ship as *.xtf files and then restored and processed on a segment by segment basis at the Skidaway Institute of Oceanography (SKIO) with Isis Sonar 5.88. The bottom tracking was adjusted manually in order to accurately follow the morphology of the seafloor and the water column was removed. Navigation data was smoothed to remove jumps in time or unrealistic changes in speed. Time-varied-gain (TVG) was applied to all files. The TVG curve was locked down on a segment showing the full range of backscatter values in the image and kept constant for the mosaicing procedure. Ship position was recorded using DGPS. Each segment was corrected for layback using a best-fit approximation to the multibeam bathymetry. The horizontal layback ranged from 0 - 31m and averaged approximately 20 m; we also applied a lateral offset of 0.19 m. The output resolution for the processed files was 0.25 m per pixel. The files were saved in UTM zone 17 coordinates and uploaded to Delph Map 2.8.

In Delph Map, the lines were added to the mosaic segment by segment. In regions of overlap for segments on adjacent lines, the best image for feature detection was visually selected before segments were merged into a single image. The image was exported as a GeoTiff file. Horizontal accuracy of the two backscatter mosaics (N-S and E-W) was estimated to be approximately 10 m.

Multibeam bathymetry data were acquired using a Reson Beabat 8101 multibeam echosounder that was hull-mounted on Whiting's Launch 1005. Data were collected along E-W tracklines using ISIS Sonar software (v5.59), processed in CARIS Hydrographic Information System (HIPS) and Hydrographic Data Cleaning System (HDCS) v4.3.2, and mosaiced in Mapinfo. Pixel size in the final mosaic was 2 m and horizontal accuracy was estimated at 5 m.

Collecting Ground Validation and Accuracy Assessment Data

Following preliminary evaluation of the backscatter mosaics, bathymetry, and available ground truth data, individual dive sites and transects were selected for typological validation in the field by scuba and towed video to support interpretation of sonar signatures. Site selection for four dives included areas in the backscatter mosaics with confusing or difficult to interpret signatures. Similarly, eight transects were selected to cross many representative sonar signatures occurring in different depths and parts of the sanctuary. In addition to these transects which were used for ground validation, four randomly placed video transects were conducted and used for refining the classification scheme (see *Developing the Habitat Classification Scheme*) and measuring thematic accuracy (see *Assessment of Classification Accuracy*). The area surveyed with video transects was maximized by using a towed camera platform called a MiniBat (pictured at left). Navigating to field sites was accomplished by uploading geographic coordinates from the mosaic for dives or transect starting points into a shipboard GPS. Using an onboard PC connected to the GPS allowed navigation using digital nautical charts. Field activities were conducted with the guidance of local experts from GRNMS and the Georgia Department of Natural Resources during August 2002. The 8 video transects for



ground truth data and the 4 randomly located transects for use in accuracy assessment covered 37 and 24 linear km respectively. Each of the accuracy assessment transects were 6 km in length. For all transects, the video camera was downward pointing and averaged approximately 2 m above the substrate during collection. A time stamp, ship velocity, tow cable length, GPS parameters, overall depth, and depth of the minibat were recorded with the video. This allowed the horizontal position of individual frames of video to be estimated to within approximately 5-10 m of their true position. The speed of the boat and frequency of GPS fixes resulted in accurately geopositioned frames of imagery every 6 to 14 meters. At each GPS fix, the percent cover of sessile benthic organisms was quantified by freezing the video frame and using a grid overlaid onto the television monitor.

The four dives resulted in the acquisition of over 200 digital still photos which were used to aid in benthic characterization at those sites. The location and a brief description of the dive sites is in Table 1.

Table 1. Description of bottom types at four dive sites in GRNMS.

Dive	Lat	Long	Depth (ft)	Description
1	31.39624	-80.88998	61	Densely colonized ledge (1-2 m elev.), sparse continuous hard bottom on top, patchy moderately colonized hard bottom below, sand waves between patches, hard bottom and sand patches are individually smaller than 10 by 10 m.
2	31.40932	-80.86893	65	Flat sand plain. Epibenthic invertebrates common.
3	31.41245	-80.91633	60	Flat sand plain. Epibenthic invertebrates common.
4	31.38164	-80.88581	64	Moderately colonized ledge (<0.5 m elev.), sparse colonization above, rippled sand below.

Developing the Habitat Classification Scheme

We created a hierarchical classification scheme to define benthic features visible in the sonar data. The specific categories and structure of the classification scheme were driven by several factors. The needs of GRNMS staff for science and management were of primary concern, however, the minimum mapping unit, spatial resolution, positional accuracy, and other technological limitations of the sonar data constrained the possible map classifications. Previous research in the area indicates that a few bottom types dominate the region including sand, ledges, and live bottom. These thematic categories were qualitative in initial studies of the area (Hunt, 1974; Henry and Giles, 1979). Later, scuba observations were used to establish quantitative classifications for live bottom areas which were denoted as sparse with 1-25% of the bottom colonized; moderate with 26-50% of the bottom colonized; or dense with 50% or greater area of the substrate colonized (Parker *et al*., 1994). In order to evaluate the ecological relevance of these quartile based categories and possibly select more appropriate quantitative criteria for benthic classification, we analyzed video tapes of bottom features and compared them to the sonar imagery. The percent colonization values for each of the geolocated frames of the video transects were overlayed onto the sonar mosaic to determine if bottom features identifiable on video have specific bathymetry and backscatter signatures that allow them to be reliably and consistently interpreted.

Of the 61 linear km of video transect data recorded, 58 km was usable for ground truth or accuracy assessment. Approximately 3 km was unusable due to either too high or too low camera altitude over the sea floor which prevented evaluation of the benthos.

To develop an understanding of the relative areas with different colonization densities and those areas that were completely covered with sand, the four randomly placed transects designated for accuracy assessment were more closely examined. Since these were randomly placed and spanned the width of the sanctuary, they can be considered as representative of bottom types in the study area and are useful for initial characterization of the sanctuary. These video data indicate that large areas of the sanctuary bottom are covered with sand. Of the 1928 geocoded video frames, 1146 or 60% were classified as

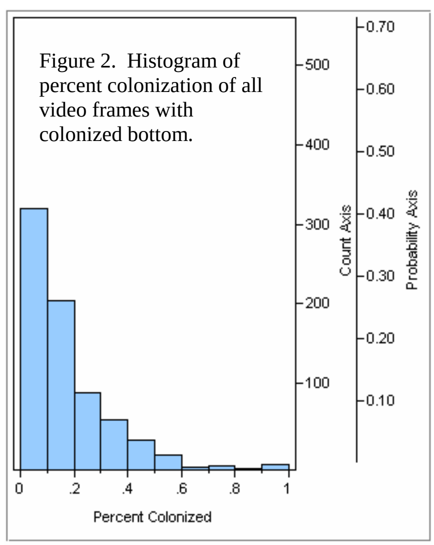


Figure 2. Histogram of percent colonization of all video frames with colonized bottom.

sand. A histogram of the percent colonization values for the remaining 782 video points indicated an exponential decline from the number of frames with 1% of the area colonized to the number of frames with 100% of the area colonized (Figure 2). It is important to note that these accuracy assessment transects were not examined in conjunction with the sonar imagery at this time. As a result, their integrity as an independent dataset for measuring thematic attributes of final maps was not compromised. Comparison of the sonar signatures (bathymetry and backscatter) overlayed with the interpreted frames of the ground truth video transects revealed that only sand waves and densely colonized ledges had consistent, easy to interpret sonar signatures. A list of these and other detectable bottom features and their description in the sonar data follows.

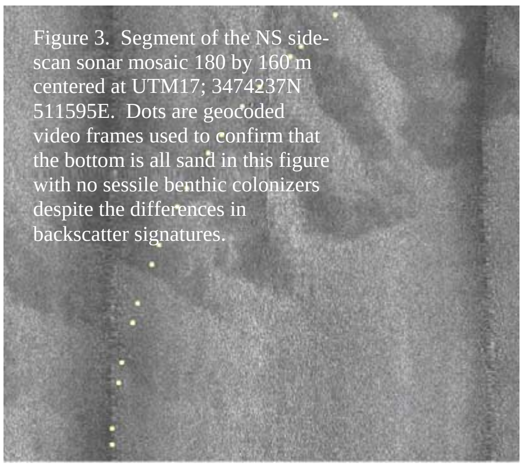


Figure 3. Segment of the NS side-scan sonar mosaic 180 by 160 m centered at UTM17; 3474237N 511595E. Dots are geocoded video frames used to confirm that the bottom is all sand in this figure with no sessile benthic colonizers despite the differences in backscatter signatures.

SAND RIPPLES: Rippled sand was easily observed and discriminated from all other bottom types in the sanctuary. The ripples clearly appear in the N-S backscatter mosaic due to their regular pattern of strong and weak sonar returns corresponding to the surface orientation of the sand waves to the sonar beams. This regular interval is evident in the lower-right region of Figure 3. The width of the alternating hard and soft sonar returns matched the wavelength of rippled sand measured *in situ*. Bathymetry for these areas is constant or gently sloping with no areas of sudden change.

SAND PLAIN: Large areas were observed to be flat sand without ripples on the video transects. The northwest to southeast oriented features of low backscatter (dark signal) separated by rippled sand in Figure 3 were observed to have no sessile benthic colonizers. Rather, the dark features were simply flat sand areas. Similarly, during a scuba survey, a large area of dark backscatter and low bathymetric relief found in the northwest region of the sanctuary was also found to be flat sand with no colonization by sessile benthic invertebrates. The video imagery and scuba surveys indicate that these sand plains have a variety of echinoderms feeding on their surface and are occupied by a diverse infauna which builds small mounds or burrows. The sonar signature of this bottom type can be distinguished from areas with sparse colonization of sessile benthic organisms by examining the variance in the backscatter signature. Sand plains typically had a low variance while sparsely colonized areas had irregular backscatter variance.

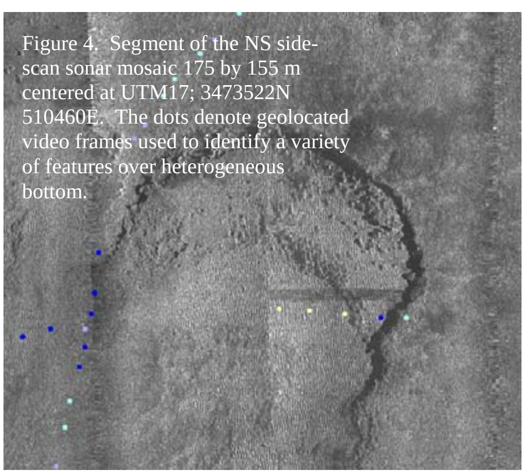


Figure 4. Segment of the NS side-scan sonar mosaic 175 by 155 m centered at UTM17; 3473522N 510460E. The dots denote geolocated video frames used to identify a variety of features over heterogeneous bottom.

DENSELY COLONIZED HARD BOTTOM: Ledges were consistently found to have the highest densities of colonization observed in the video transects. Percent cover measurements of the bottom in the video frame analysis indicated that these areas had at least 60% coverage of sessile benthic organisms and in several cases achieved 100% coverage. The precise vertical resolution of the multibeam bathymetry made identification of even small ledges (< 0.5 m) a simple task. By overlaying the backscatter data it was possible to discern an area along the upper surface of each ledge that is densely colonized and has a low value of backscatter intensity. Sonar shadows used to identify these ledges and the sand waves in the basins commonly found below each ledge are visible in Figure 4. This bottom type accounted for only 3% of the observations in the video data.

SPARSELY COLONIZED HARD BOTTOM: The vast majority (70%) of the colonized frames of the video imagery have between 1 and 20% coverage of sessile benthic organisms (Figure 2). Another 27% of the frames with colonized bottom had between 20 and 60% of the substrate occupied. These areas can be easily distinguished from sand waves and densely colonized ledges in the sonar imagery but not as easily from flat sand since backscatter signatures of sparsely colonized area can be quite variable. Heterogeneity in backscatter signatures as a result of variable bottom composition, roughness, and the geometry of the sonar beam angle with the substrate prevented discrimination of bottom types into multiple categories when 1 to 60% of the substrate was colonized.

General Description of the Classification Scheme

Based on the results of the combined examination of the video data and the sonar imagery it was deemed possible to consistently identify four bottom types from the available data: sand plain, rippled sand, sparsely colonized hard bottom, and densely colonized (ledges) hard bottom. A hierarchical classification scheme was created around these categories that defines bottom types within two major groups; unconsolidated sediment and colonized hard bottom. A definition and example imagery for each bottom type follows.

Unconsolidated Sediment: Loose sand or small shell fragments with less than 1% of the area colonized by sessile invertebrates. No mud or sediment with finer grain size is found within the project area.

Sand Plain: Stable sand covering a flat region. Thickness is variable but may be only a few centimeters overlying flat limestone. Bioturbation is often present from polychaetes, echinoderms, and burrowing fishes and ranges from reworking of surface material to mound building and other excavations.

Rippled Sand: Sediment deposited in sufficient thickness such that regular ridges or waves are formed. The ridges generally run from north to south in this region due to the orientation of tidal currents. Typically, these sand waves are 6-10 cm in height from crest to trough and are 40-60 cm in length from crest to crest. Troughs are often dominated by coarser material such as shell fragments while crests are primarily composed of sand.

Colonized Hard Bottom: Bottom composed of exposed limestone substrate that is colonized with an assemblage of sessile benthic organisms such as soft corals, sponges, and tunicates. Density of colonization may be sparse or continuous. The limestone may be flat with little vertical relief or include ledges, overhangs, and other changes in bathymetry.

Sparsely Colonized Hard Bottom: Bottom composed of partially exposed limestone substrate that is colonized with a sparse assemblage of sessile benthic organisms such as soft corals, sponges, and tunicates. Between 1 and 60 percent of the bottom area is colonized. A thin veneer of sand 1-2 cm thick may cover much of the bottom but is thin enough to allow sessile benthic organisms to attach to the limestone. Typically, this bottom type covers large contiguous areas of very low relief.

Colonized Hard Bottom: Bottom composed of exposed limestone substrate that is colonized with an assemblage of sessile benthic organisms such as soft corals, sponges, and tunicates. Density of colonization may be sparse or continuous. The limestone may be flat with little vertical relief or include ledges, overhangs, and other changes in bathymetry.

Densely Colonized Hard Bottom: Bottom composed of exposed limestone substrate that is colonized with a nearly continuous coverage of sessile benthic organisms such as soft corals, sponges, and tunicates. Between 60 and 100 percent of the bottom is colonized. Typically, only ledges and other areas of bathymetric relief are densely colonized. In contrast, flat limestone typically has only a sparse colonization of sessile invertebrates. Ledges typically have a vertical relief of 0.5 up to 2 m.

Digitizing Benthic Maps

The bathymetry, N-S, and E-W oriented backscatter mosaics were loaded into ArcView 3.2 with the Habitat Digitizer extension activated (Kendall *et al*., 2001). The minimum mapping unit (MMU) restriction in the Habitat Digitizer was set to 100 m^2. This MMU dimension was selected based on the resolution of the sonar data, the needs of the GRNMS staff, and the extent of the area to be mapped. Digitizing scale was set to 1:1000 in the Habitat Digitizer. Preliminary evaluation of the sonar data sources indicated that at this scale, boundaries of all the bottom types in the classification scheme could be readily identified. At finer scales than 1:1000 the individual pixels of the backscatter mosaic are visible, as a result, additional zoom does not improve resolution, interpretability, or line placement.

Using the Habitat Digitizer, polygon boundaries were delineated around backscatter signatures in the N-S sonar mosaic corresponding to bottom types in the classification scheme. This was often accomplished by first digitizing a large polygon such as a sand plain and then appending new polygons to the initial polygon or splitting out smaller polygons within. Each new polygon was attributed with the appropriate bottom designation according to the classification scheme. All lines were digitized on the N-S oriented tracklines since areas with sand ripples were easily distinguished in this mosaic. This bottom type was much more difficult to detect in the E-W mosaic due to the geometry of the sonar beam angle and the orthogonal N-S orientation of the sand waves. It is believed that the positional accuracy of polygon boundaries is similar to that of the mosaics since delineation was performed directly on the digital imagery. By alternating between the two backscatter mosaics, a plot of backscatter and bathymetric variance, and the ground truth data from georeferenced video frames, the edges of benthic types in the classification scheme could be easily interpreted. Additional collateral information including previously completed benthic maps, dives, and video transects (excluding the accuracy assessment transects) were also used to assist with feature delineation and assignment of thematic attributes. A description of how a variance map for backscatter and bathymetry were generated and used to aid in mapping follows.

Backscatter Variance

There were some consistent patterns associated with the variance of backscatter signatures of bottom types that could be used to assist in identifying them during polygon delineation. Standard deviation of backscatter signatures was calculated based on all pixel values in the N-S oriented mosaic within a 3 m neighborhood. The resulting grid was created with a resolution of 0.25 m. Comparison of this new grid with the other data sources showed that rippled sand areas have a characteristic variance in backscatter due to the regularly occurring pattern of high and low sonar returns that occurs with the same periodicity as the crests and troughs of sand waves (~50 cm). Areas of flat sand and those directly beneath the sonar fish had low variance in backscatter signatures. Ledges and sparsely colonized areas had highly heterogeneous values. This finding would have provided an excellent means to begin an automated classification process (rather than visual) for discriminating between rippled sand, sand plains, and hard bottom were it not for the low contrast areas beneath the sonar fish. Unfortunately, backscatter data were not collected with sufficient overlap to allow these values directly below the sonar fish to be replaced with values from adjacent tracklines during the mosaicing process.

Bathymetric Variance

The seafloor within GRNMS is largely flat and featureless with depths ranging between 14.5 and 21 m with an average depth of 18 m. The limestone ledges, slopes, and overhangs in the region constitute a small fraction of the total sanctuary area but have by far the highest colonization of invertebrates and fishes of any bottom type in the area. Dives and video data indicate that the more abrupt the change in relief, the more dense the colonization of sessile organisms. To focus on these important changes in relief during delineation of bottom types, a map of bathymetric variance was created. Using the original 2 m bathymetry grid as a spatial framework, standard deviation of the depth values for all grid cells within 6 m of each 2 m grid cell was calculated and used to create a map of depth variability. This approach resulted in high values for cells on or near ledges and low values for cells surrounded by flat bottom. The 6 m radius of analysis was selected since this distance allowed inclusion of a neighborhood of cells in deviation calculations that was consistent with the MMU and sufficiently resolved to identify ledge habitat.

Following processing of the field data, polygon boundaries and bottom classifications were created using the Habitat Digitizer. This draft of the benthic maps was then presented for review to local experts at SKIO in Savannah, Georgia. Review session participants included members of the local research and management community. No edits were recommended during the meeting due to the high resolution of the draft maps and the lack of recent bottom characterization data with adequate georeferencing. As a result, the draft maps underwent final QA/QC and were saved as ArcView shapefiles. Thematic accuracy was assessed for these final maps.

Assessment of Classification Accuracy

Assessment of thematic accuracy after map production is a critical part of any mapping project. Mapmakers want to know how reliably a given habitat type can be classified, this is called "producers accuracy". Map users want to know what percentage of the polygons labeled with a specific habitat type is classified correctly, this is called "users accuracy" (Congalton, 1991). Such assessment is necessary to maintain acceptable standards of quality and to quantify the reliability of final benthic maps. Thematic accuracy of the benthic maps of GRNMS was evaluated using a random-start, systematic video survey comprised of four parallel transects, each approximately 7.5 km in length and separated by 1-1.5 km.

Accuracy was quantitatively evaluated for two of the four bottom types that were mapped, namely sparsely colonized live bottom and unconsolidated sediment. All bottom types could not be quantitatively evaluated due to limitations of the accuracy assessment dataset. Unconsolidated sediment could be readily discriminated from colonized frames in the video data, however, rippled versus flat sand could not be reliably differentiated. As a result, accuracy of map delineations was measured most general level of the classification scheme for the unconsolidated sediment categories. In addition, densely colonized live bottom comprised less than one percent of the mapped area and similarly, was found to be in only a fraction of one percent of the video frames used for accuracy assessment. This low sample size prevented statistically robust evaluation of this classification although qualitative assessment of densely colonized points is considered.

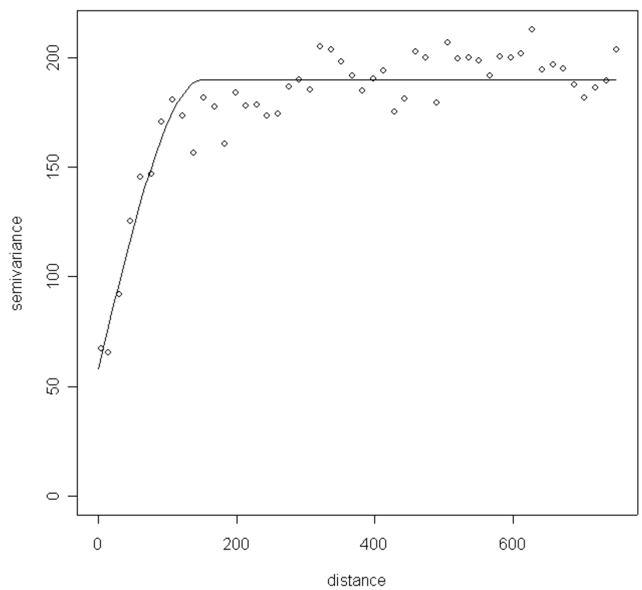
The accuracy assessment dataset was collected in August 2002, 13 months after the sonar data were obtained. This short time interval and the observation that no major storms were documented for this period minimized the possibility that sediment could have shifted and habitat types changed significantly in the project area between the time of acquisition of the sonar data and collection of the accuracy assessment data.

A combination of spatial autocorrelation inherent to neighboring points along transect data, the presence of habitat heterogeneity at a scale finer than the MMU, and potential misalignment of video and sonar data required the modification of typical accuracy assessment techniques for this project. Positional error of maps and/or accuracy assessment data can result in conservative bias (i.e. map accuracy is underestimated) when standard accuracy assessment procedures are used (Verbyla and Hammond, 1995). Accuracy assessment data is often collected at a finer spatial scale than mapped polygons and must be cautiously applied during accuracy assessment within the context of the MMU. Positive spatial autocorrelation, the condition where nearby samples tend to have similar values, is common for ecological variables such as habitat classification and, if uncorrected, can have an adverse impact on statistical tests (Legendre, 1993). Positive autocorrelation violates the assumption of independence and biases statistical tests by effectively overestimating the true sample size (Aubry and Debouzie, 2000). Points along a transect used for accuracy assessment must be far enough apart such that they are statistically independent.

Problems associated with misalignment of map and reference data as well as mismatch between the scale of video data and the MMU were minimized by following a specialized accuracy assessment procedure. Following previous studies that have used transect data for accuracy assessment (e.g. Muller *et al*., 1998), we based the size of accuracy assessment sites for both the transect data and the benthic map on the potential positional error of those data sets which was combined and estimated to be +/- 20m. Specifically, the benthic habitat map was rasterized to a 2.5m grid, and individual pixels were removed from the accuracy assessment process if any pixels within a 10m radius contained a different habitat type. This step removed 13% of the overall map area. Similarly, individual video frames were removed from the analysis if the previous and subsequent video frames along the transect did not have the same habitat type. Three geocoded video frames in a row cover approximately 20m. This step removed 570 (21%) out of 2694 data frames. This resulted in areas being included in the accuracy assessment only if they exhibited relatively homogeneous bottom types at the scale of the positional accuracy of the source data and MMU. Although this technique minimizes the impact of spatial misalignment on the accuracy assessment, it also reduces the scope of inference to those portions of the map that were not removed because of small scale heterogeneity.

Problems associated with autocorrelation of accuracy assessment points nearby each other along transects were eliminated by analyzing the spatial autocorrelation structure of the transect data and selecting points for accuracy assessment that were far enough apart along the transects such that the assumption of statistical independence was met. First, Geary's C and Moran's I statistics were calculated to test for the presence of significant spatial autocorrelation. Tests were conducted using CrimeStat (Levine, 2002). Moran's I is the 'standard' autocorrelation statistic and provides a global (i.e. across the study area) test of spatial autocorrelation. Geary's C is more sensitive to autocorrelation within small neighborhoods. Since both tests showed highly significant ($p < 0.001$) positive autocorrelation the following procedures were used to determine the minimum distance required between video frames to select independent samples from the transect data:

1) The empirical variogram was calculated for the video transect data using the statistical package R v1.6.2. The empirical variogram describes the decrease in relatedness between pairs of points as a function of distance. Spatial autocorrelation statistics were Moran's I 0.2376 ($p<0.001$) and Geary's C 0.7649 ($p<0.001$). Variogram parameters for video transect data were nugget = 58, partial sill = 132, and range (m) = 150.
2) A spherical variogram model (line in figure at right) was fit to the empirical variogram (points in figure at right). The range parameter of this model represents the distance at which autocorrelation becomes negligible. Pairs of points separated by a distance greater than the range can be considered essentially independent. The spherical model was chosen based on the observed pattern of the empirical variogram and because it is the only model which provides a precise non-arbitrary estimate of the range.
3) Based on the calculated range, video frames were selected for accuracy assessment at intervals of 150m.



Bottom type recorded for each selected series of three adjacent video frames was overlaid onto the benthic maps and compared against the classification assigned during visual interpretation. After comparing the map classification to each video site, an error matrix was produced displaying both errors of inclusion and exclusion (Table 3). In addition, overall accuracy, users and producer's accuracy, and the Kappa statistic (measure of map accuracy relative to a map with classifications randomly assigned expressed as a percent) are reported. Although the video survey design was a random start systematic sample, estimates of Kappa and its standard error are based on formulas for random multinomial samples. Stehman (1992) shows, however, that the bias in the estimate of Kappa for a systematic survey is negligible. Bias in the standard error of Kappa is harder to predict as it depends on the extent to which any periodicity in the underlying map matches the period of the systematic sample.

Note that the error matrix contains comparisons for unconsolidated sediment and sparsely colonized hard bottom only. Recall that, due to the small area of densely colonized hard bottom (0.6% of the mapped area) and the limits of the video transect data, insufficient samples were available for quantitative accuracy assessment. Only seventeen out of the 2,694 video frames (0.6%) were classified as densely colonized hard bottom. Ideally, this problem could be eliminated by stratifying the collection of accuracy assessment data according to bottom types once an initial map of the area has been produced. Unfortunately, logistics prevented such an arrangement from being possible here.

Results

The entire bottom area of GRNMS was mapped. A summary of the area for each of the bottom types reveals that unconsolidated sediments dominate the bottom of this region and that densely colonized ledges account for only a fraction of one percent of the total area (Table 2). Approximately 450 polygons were attributed as densely colonized bottom.

Table 2. Summary of the number and area of polygons for each map category.

Classification	no. polygons	area km^2	% of area
Flat sand	1538	4.7	8
Rippled sand	1516	40.0	67
Sparsely colonized live bottom	1181	14.9	25
Densely colonized live bottom	447	0.4	<1
	4682	60	100

Overall map accuracy was 94.8 percent. Both unconsolidated sediment and sparsely colonized bottom had a high thematic accuracy (Table 3). The Kappa statistic was 0.88 +/- 0.04 (SE) indicating significantly better than random prediction accuracy ($p < 0.001$). However, because of the specialized procedure used here, the scope of inference for this accuracy assessment is limited to those regions (87%) of the map that did not display fine-scale spatial heterogeneity.

Table 3: Error matrix. Numbers in the matrix indicate class coincidence, (U) indicates users accuracy, and (P) indicates producers accuracy based on analysis of 135 points.

Mapped Habitat Type	**Video Observed Habitat Type:** *Unconsolidated Sediment*	*Sparsely Colonized Hard Bottom*
Unconsolidated Sediment	88 96.7%(U) 95.7%(P)	3
Sparsely Colonized Hard Bottom	4	40 90.9%(U) 93.0%(P)

The seventeen video frames classified as densely colonized live bottom occurred in two clusters, both of which crossed areas mapped as such within the spatial accuracies of these data. In addition, one site was classified as dense in the benthic map that was crossed by a transect but not scored as dense in the video. Five additional polygons attributed as densely colonized have been visited in the field and were confirmed to have that habitat type. Unfortunately, eight points does not provide a statistically robust sample size to determine if densely colonized live bottom was successfully interpreted. Since this is an important classification, an alternative metric for evaluating the delineation of densely colonized ledge habitat was explored. Recall that bathymetric variance was used to aid in delineation of thematic classes. Sand plains, rippled sand, and sparsely colonized hard bottom were all defined in part by very low or no slope. According to the classification scheme only densely colonized hard bottom, which generally only occurs on or near ledges, has high slope or sudden changes in bathymetry. One way to simply validate that polygons labeled as densely colonized encompassed areas of high depth relief and those labeled as sand or sparsely colonized covered areas of low relief is to examine the average bathymetric deviation of polygons labeled with each classification. Figure 5 shows that polygons labeled densely colonized had much higher depth variance than those labeled other categories which occurred over relatively flat bottom. Because bathymetric variance was used to aid in delineation of polygon boundaries, this analysis simply confirms that densely colonized polygons were successfully digitized to encompass areas of significant depth relief. This provides additional, qualitative validation that this important bottom type was correctly delineated; however, only through additional field work, including randomly selected site visits, can quantitative evaluation of users and producers accuracy be accomplished.

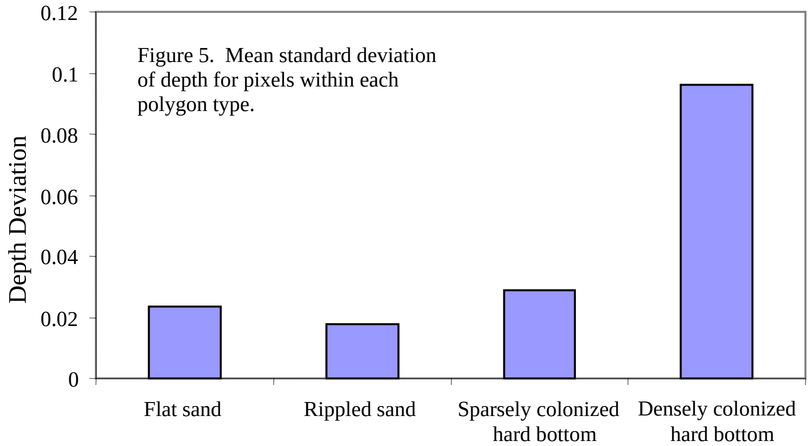


Figure 5. Mean standard deviation of depth for pixels within each polygon type.

Discussion

The accuracy assessment demonstrates that the habitat maps successfully differentiate between unconsolidated sediment and colonized bottom for most of the area mapped. Positional inaccuracies and rarity of densely colonized habitat prevented accuracy assessment within areas of fine scale habitat heterogeneity and densely colonized regions although qualitative evidence indicates that this bottom type was correctly delineated. This indicates that the benthic maps of GRNMS have a very high degree of thematic accuracy and are suitable for a variety of management and research applications.

Previous researchers estimated that 18% of the GRNMS bottom was covered with sand, 58% consisted of live bottom, and another 24% was ledge habitat (Table 4)(Hunt, 1974; Parker *et al*., 1994). Another study, citing a Georgia Department of Natural Resources map, estimated that 53% of the bottom was bare sand, 13% was sparsely colonized live bottom, and the remaining 34% was moderately colonized hard bottom (Hopkinson *et al*., 1991). These estimates, while quite different from each other were based on the limited point assessments, grab samples, and sonar technology available during previous decades. The differences between the areas tabulated are in part influenced by the lack of rigorous quantitative criteria for map categories, differences in definitions between classifications, and some amount of real change that occurred in the region's habitats during the time period between creation of the two maps.

Table 4. Relative area of different habitat types within GRNMS from the current study and two previous studies.

	Current Study	Hunt, 1974 in Parker *et al*., 1994	GA DNR in Hopkinson *et al*., 1991
Sand	75%	18%	53%
Some colonization/live bottom	25%	58%	13%
Dense or moderate colonization/ledge habitat	0.6%	24%	34%

In comparison, this study found three quarters (75%) of the GRNMS bottom was sand, 25% showed some colonization, and only 0.6% was densely colonized. Differences in classification categories make it difficult to compare the two colonized categories among different studies. The percentage of bottom classified as sand, however, is clearly greater in the current study than in previous reports. Because previous studies vastly differ from the current assessment in methods and resolution, comparison for the purposes of change detection is not feasible. Certainly, changes have occurred in the relative proportions of the different benthic types in the study area since the first assessment in GRNMS in 1974, however, only now with the advent of more advanced sonar technologies and the map and protocol devised here has a fine-scale baseline been established against which future assessments can be compared.

The majority of the seafloor on the continental shelf lies beyond the detection limits of aerial or satellite mapping technologies due to water depth and/or turbidity. The approach and mix of technologies used for this mapping project can be easily adapted and applied to produce accurate maps of many such areas. The software we used allows creation of a customized classification scheme and delineation of maps with specific scale and resolution characteristics. The video transect approach to collection of field data requires a modified procedure for accuracy assessment but maximizes the spatial area that can be covered during field operations in deeper water. The use of both backscatter and bathymetric variance provides more insightful visualization of benthic features during interpretation than the use of raw sonar values alone and will ultimately be the key to automated classification techniques.

Additional areas of research that should be explored to provide a more complete assessment of habitats within GRNMS include directed accuracy assessment of densely colonized hard bottom to quantify the accuracy of delineations for this important bottom type. In addition, *in situ* benthic characterization will allow differences within the four mapped categories to be quantified. For example, the 447 polygons attributed as densely colonized hard bottom are not identical. Measuring the differences in ledge height, colonization density, and composition of fish and invertebrate assemblages at randomly sampled ledge sites will provide a greater understanding of the variability in these important benthic structures for the Georgia bight and southeastern shelf communities.

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